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(54) A radiation detector including a scintillator array.

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(73) Proprietor : HAMAMATSU PHOTONICS K.K.
1126-1 Ichino-cho
Hamamatsu-shi
Shizuoka-ken (JP)

(72) Inventor : Uchida, Hiroshi
c/o Hamamatsu Photonics K.K.,
1126-1 Ichino-cho
Hamamatsu-shi, Shizuoka-ken (JP)
Inventor : Omura, Tomohide
c/o Hamamatsu Photonics K.K.,
1126-1 Ichino-cho
Hamamatsu-shi, Shizuoka-ken (JP)

(74) Representative : Rackham, Stephen Neil et al
GILL JENNINGS & EVERY,
Broadgate House,
7 Eldon Street
London EC2M 7LH (GB)

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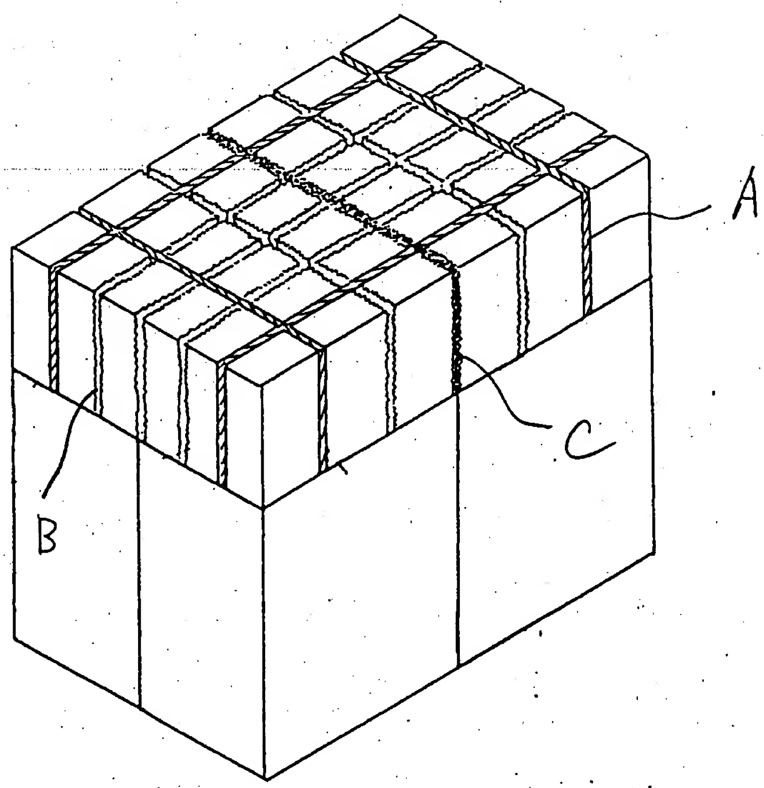
FIG. 7



Description

This invention relates to a radiation detector, and more particularly to a radiation detector using a scintillator array such as a positron emission tomography for detecting a location of radiation incident to the scintillation array.

There has been developed a new technical field of nuclear medicine for diagnosing and curing a disease of a human body using radioisotope (RI). As one of techniques which belong to this technical field has been known a positron emission tomography (PET) for detecting an emitting location of radiation such as gamma-rays with a scintillator.

The positron emission tomography is a type of nuclear imaging apparatus used especially in medical diagnostic and researching imaging. In the positron emission tomography, one type of radioactive compound (a drug labelled with a nuclide having positron emission capability) is administered to a patient or other living organism under surveillance. Positrons are positively charged particles, and are emitted from the nuclide of radioactive compound as isotope decay within the body. Upon emission, the positron encounters an electron, and both are annihilated. As a result of one annihilation, gamma-rays are generated in the form of two photons which travel in approximate opposite directions (about 180 degrees) to one another. Traditionally, the apparatus is disposed so as to surround the body to accumulate information concerning the lines of travel of the emitted photons at different angles around the body under surveillance and process this information through a computer, whereby a tomographic image of the distribution and concentration of the nuclide is obtained and at the same time is two dimensionally displayed together with a sliced image of the body. In this connection, the PET scanner can observe and quantify biochemical and physiological changes that occur naturally and in disorder in the human body or the like.

An amount of the drug to be administered into the patient or the like is preferably smaller to avoid an influence of the nuclide on the body, however, a smaller amount of the drug causes the emitted radiation to be more reduced in intensity. Accordingly, the radiation detector is required to effectively detect the radiation of weak intensity emitted from the body.

In order to satisfy such a requirement in the art, a gamma-rays detector having an inorganic scintillation crystal such as thallium-activated sodium iodide (NaI (Tl)), $Bi_4Ge_3O_{12}$ (BGO), CsF or the like as a scintillator has been utilized as a radiation detector. The gamma-rays detector comprises plural scintillators arranged one or two-dimensionally for converting gamma-rays emitted from the body to a dispersely-emitting scintillation light, and plural photomultiplier tubes (PMT) optically coupled to th scintillators for converting th scintillation light int electrons and multiplying them. In this gamma-rays detector, the scintillation light emitted from one scintillator of the one- or two-dimensionally arranged scintillator array is distributed to the other scintillators in a predetermined distribution ratio and then guided to the photomultiplier tubes corresponding to the respective scintillators, so that amplified electrical signals having statistical information on an incident position of the gamma-rays to the scintillator array (that is, a scintillation location) are outputted from the respective photomultiplier tubes. The position of the gamma-rays incident to the scintillator array (the scintillation location) is statistically determined on the basis of the electrical signals. The gamma-rays detector thus constructed enables a detection resolution to be more enhanced, however, simultaneously causes the scintillation light to be attenuated through a distributing process in which the scintillation light generated in one scintillator is distributed to the other scintillators and a guiding process in which the distributed scintillation lights is guided to the photomultiplier tubes. Accordingly, it has been required for this type of gamma-rays detector to prevent the attenuation of the scintillation light particularly through the distributing process and optimumly carry out the distributing process.

Various types of radiation detectors each utilizing an scintillator array and a photomultiplier tube in combination, for example as shown in Figs. 1 to 3, have been proposed in order to satisfy the above requirement.

The radiation detector as shown in Fig. 1 includes a scintillator array 1 comprising one-dimensionally arranged four scintillators 1_1 to 1_4, and two photomultiplier tubes 2_1 and 2_2 one of which is optically coupled to a half (two scintillators) of the scintillator array 1 and the other of which is optically coupled to the other half (the other two scintillators). The scintillator array 1 is provided with a reflection layer at each of interfaces (coupling surfaces) 3_1 and 3_3 between the neighbouring scintillators 1_1 and 1_2 and between the neighbouring scintillators 1_3 and 1_4 and further provided with a predetermined area ratio of a reflection layer and a transmission layer at an interface (coupling surface) 3_2 between the neighbouring scintillators 1_2 and 1_3. Accordingly, the scintillators 1_1 and 1_4 are optically separated from the scintillators 1_2 and 1_3 through the reflection layers, respectively, but the scintillators 1_2 and 1_3 is optically coupled through the transmission layer to each other. That is, a scintillation light emitted from one of the four scintillators 1_1 to 1_4 is not distributed (transmitted) to the other scintillators through the reflection layers, while a scintillation light emitted from one of the scintillators 1_2 and 1_3 is distributed (transmitted) through the transmission layer to each other. In this case, a distribution ratio of the scintillation light corresponds to the area ratio of the reflection and transmission layers provided at the interface (coupling surfac) 3_2. This radiati n

detector is described in detail in Japanese Unexamined Published Patent Application No. 62-135787.

The radiation detector as shown in Fig. 2 includes a scintillator having plural grooves (slits) 4 obtained by vertically cutting the scintillator in different depths, and two photomultiplier tubes, one of which is optically coupled to a half of the scintillator 1 and the other of which is optically coupled to the other half. The grooves 4 are provided with reflection agent, and serves to guide a scintillation light generated within the scintillator toward the photomultiplier tubes while distributing the scintillation light to the other scintillators and the corresponding photomultiplier tubes in a suitable distribution ratio. This type of radiation detector is described in detail in USP 4,749,863, and in "IEEE Transactions on Medical Imaging", Vol. 7, No. 4, 1988, pp264-272.

The radiation detector as shown in Fig. 3 includes a scintillator array comprising plural scintillators 1_{11} to 1_{44} which are three-dimensionally arranged, plural photo multiplier tubes 2_1 and 2_2 and a light guide 5, sandwiched between the scintillator array and the photomultiplier tubes, for guiding a scintillation light emitted from the scintillator array to the photomultiplier tubes. As the light guide may be used one as shown in "IEEE Transactions on Nuclear Science" Vol. 33, No. 1, February 1986, pp446-451, pp460-463. In this type of scintillator array, the interfaces (coupling surfaces) between the respective neighbouring scintillators are filled (or coated) with the reflection agent. This type of radiation detector is described in detail in Japanese Unexamined Published Patent Application No. 62-129776, in "IEEE Transactions on Nuclear Science", Vol. 33, No. 1, February 1986 and in "IEEE Transactions on Medical Imaging", Vol. 7, No. 4, December 1988. In place of the flat-plate type light guide, a light guide comprising plural segments each having a complicated shape as described in "IEEE Transactions on Nuclear Science", Vol. NS-34, No. 1, February 1987 may be used to distribute a scintillation light emitted from one of the scintillators to the other scintillators in different distribution ratios.

A similar detector is shown in WO 86/03596. In this detector, the scintillator is divided by a number of grooves which are filled with a reflective material to control the transmission of light.

In all of the radiation detectors as described above, the interfaces (coupling surfaces) between the neighbouring scintillators are filled (or coated) with the reflection agent to adjust the distribution of scintillation light between the respective neighbouring scintillators. The reflection agent has a capability of reflecting incident light therefrom with no leak, but has the disadvantage of also absorbing some of the light. This light-absorption becomes significant as the scintillator or scintillator array is more minutely segmented into plural scintillator units. Further, particularly in a case where a light guide is provid d betw en the scintillator array and the photomultiplier tubes as shown in Fig. 3, light-absorption also occurs in the light guide. These effects result in the scintillation light being attenuated before it is transmitted to the photomultiplier tubes. Such attenuation of the scintillation light emitted from the scintillator array (that is, an optical loss) causes energy resolution and timing resolutions to be lowered, and further causes a discriminating characteristic of each scintillator to be degraded.

GB-A-2204769 discloses a scintillator which is provided with two sets of grooves, which divide the scintillator into a number of light guides. One set of grooves is provided at the upper part of the scintillator, the other set at the lower part of the scintillator, with a region between having no grooves. In the region of the grooves, light is not able to be transmitted transversely, where as light may be transmitted transversely where there are no grooves. Accordingly, the detector is able to detect the depth of the radiation.

According to this invention a radiation detector for detecting the position of incident radiation, comprises:

a scintillator array having a plurality of scintillator elements or generating scintillation light upon incidence of radiation to them, each scintillator element having a radiation receiving surface, a light-emitting surface for emitting light guided through the scintillator element in a first direction, and a light-distributing surface for transmitting part of the scintillation light to an adjacent scintillator element a second direction, substantially perpendicular to the first direction to distribute scintillation light to other scintillator elements with a predetermined distribution ratio, the light-distributing surface serving as a coupling surface to optically couple each scintillator element to an adjacent element and

a plurality of photomultiplier tubes optically coupled to the scintillator array wherein each photomultiplier tube is optically coupled to the light-emmiting surfaces of a plurality of scintillator elements for receiving the scintillation light and converting the scintillation light into an amplified electrical signal representative of the incident position of the radiation on the scintillator array;

characterised in that each of the light-distributing surfaces serves as a coupling surface for optically coupling each scintillator element to an adjacent element, each adjacent element, each of the light transmitting surfaces having a roughened surface, a mirror-polished surface or both, for transmitting the scintillation light with a pre-determined degree of transmissivity to control the distribution ratio of the scintillation light transmitted between from neighbouring scintillator elements.

A detector in accordance with this inv ntion has a simpl construction for accurat ly det cting a radi-

ation-emitting location. Also the optical loss is remarkably reduced.

The scintillator array may comprise an assembly of plural scintillator elements or a scintillator having plural grooves therein. When the scintillator array comprises the assembly of the plural scintillators, a scintillating portion corresponds to a scintillator, and the distribution region comprises both coupling surfaces of two adjacent scintillators. When the scintillator array comprises a scintillator having plural grooves therein, the scintillating portions correspond to any portions other than confronting walls defining the grooves in the scintillator and the distribution region comprise the confronting surfaces and spaces therebetween of the grooves.

Embodiments of detectors in accordance with this invention will now be described and contrasted with the prior art with reference to the accompanying drawings; in which:-

Fig. 1 shows a conventional radiation detector having an assembly of plural scintillators;

Fig. 2 shows another conventional radiation detector having a scintillator having plural grooves therein;

Fig. 3 shows another conventional radiation detector in which a light guide is provided to the radiation detector as shown in Fig. 1;

Figs. 4(A) through 4(F) show various models of surface condition and coupling condition according to this invention;

Fig. 5 shows a first embodiment of the radiation detector according to this invention;

Fig. 6 shows a second embodiment of the radiation detector according to this invention: and

Fig. 7 shows a scintillator arrangement of a third embodiment of the radiation detector.

Like the conventional radiation detector, in a radiation detector according to this invention, a scintillation light emitted from one of scintillators is distributed to the other scintillators in a predetermined distribution ratio and then the distributed scintillation lights are guided to plural photomultiplier tubes to obtain amplified electrical signals representing an emitting location of the scintillation light. However, unlike the conventional radiation detector, the distribution ratio of a scintillator array of this invention is not adjusted with reflection agent, but by means of the following two factors (surface condition and a coupling condition of an interface (a coupling surface) between respective neighbouring scintillators). The surface condition is defined by a sectional profile of the coupling surface such as a rough surface, a mirror-polished surface or the like, and the coupling condition is defined by a substance (or refractive index of the substance) to be provided to the coupling surface such as an air, or a coupling agent such as water, silicone oil r RTV rubber. In this case, the refractive indexes f the scintillator (BGO), silicone oil (RTV rubber) and water are 2.15, 1.45 and 1.33, respectively. Accordingly, the distribution ratio is freely variable by changing the surface condition of each coupling surface and/or changing the substance to be provided between the neighbouring scintillators.

Figs. 4(A) to 4(F) show various types of models applicable to a scintillator array used in this invention. In order to explain the change of the light-transmissivity through the coupling surface in accordance with variation in the surface condition and the coupling condition of the scintillators 1a and 1b, each model is shown to have a common construction in which two scintillators 1a and 1b are optically coupled to each other through coupling surfaces 3a and 3b thereof.

A first model as shown in Fig. 4(A) includes two scintillators each having a roughly-designed coupling surface. A second model as shown in Fig. 4(B) includes a scintillator having a mirror polished coupling surface and the other scintillator having a roughly-designed coupling surface. Further, a third model as shown in Fig. 4(C) includes two scintillators each having a mirror-polished coupling surface. Air is filled in a gap between the faced coupling surfaces of the scintillators in each of the first to third models, that is, an air layer is provided between the coupling surfaces.

With respect to the surface condition, the light-transmissivity through the coupling surface, that is, the distribution ratio of light is increased in each coupling surface as a occupied area of the rough coupling surface is increased or as the coupling surface of the scintillator is rougher. Accordingly, the light-transmissivity through the coupling surfaces of the neighbouring scintillators is decreased in the order of the first to third models. That is, the first model having two rough coupling surfaces has the highest light-transmissivity, while the third model having two mirror-polished coupling surfaces has the lowest light-transmissivity. Further, a degree of the roughness of the coupling surface may be adjusted by changing the diameter of grinding particles which are used to grind the coupling surface. The desired size of the grinding particles is preferably # 1000 in the JIS (Japan Industrial Standard).

In a case where the two scintillators having different surface condition are used as shown in the second model, a transmissivity of light (m) which is transmitted from the scintillator having the rough coupling surface 3b to the other scintillator having the mirror-polished coupling surface 3a is a little higher than that of light (n) which has an opposite transmission direction to that of the light (m).

In addition, the light-transmissivity between the neighbouring scintillators is more finely adjusted by changing an area ratio of the mirror polished and rough surfaces to be formed on a coupling surface f each scintillator. Fig. 4(D) shows a fourth model in-

cluding two scintillators each having a coupling surface on which both of a mirror-polished surface portion S1 and a rough surface portion S2 are formed in each scintillator in a predetermined area ratio (S1:S2). In this model, the mirror-polished surface portion and the rough surface portion on the coupling surface of one scintillator are completely confronted to those on the coupling surface of the other. That is, the fourth model as shown in Fig. 4(D) corresponds to a model in which a combination of the first and third models as shown in Figs. 4(A) and 4(C) is applied to each coupling surface. However, a confronting relationship between the mirror-polished surface and rough surface portions is not limited to the above model. For example, another confronting relationship as shown in Fig. 4(B), in which a mirror-polished surface portion on a coupling surface confronts a rough surface portion of the other coupling surface, may be adopted in combination with the confronting relationships as shown in Fig. 4(D). Further, Fig. 4(E) shows a fifth model including a scintillator having a groove therein. In this model, the faced inner walls of the groove serves as coupling surfaces, and the light-transmissivity through the coupling surfaces is changed by changing a depth of the groove.

The surface condition between the neighbouring scintillators is adjusted by utilizing the first to fifth models alone or in combination to more finely change the light-transmissivity between the scintillators, that is, the distribution ratio of a scintillation light.

In addition to the above manner, the light-transmissivity between the neighbouring scintillators can be more minutely changed by changing a refractive index of a gap between the coupling surfaces of the neighbouring scintillators.

In the first to fifth models, air is filled with each gap between the respective coupling surfaces. On the other hand, in a sixth model as shown in Fig. 4(F), an optical coupling agent 6 such as silicone oil, silicone grease or water is filled in the gap between the neighbouring coupling surfaces or is coated to the coupling surfaces. The coating or filling of the optical coupling agent having a higher refractive index than the air to the coupling surfaces or in the gap therebetween enables the light-transmissivity therebetween to be higher than when air is filled in the gap, and thus the distribution ratio of the light is increased.

Figs. 5 and 6 show two embodiments of the radiation detector according to this invention.

The radiation detector of the first embodiment includes a pair of photomultiplier tubes 21 and 22, and a scintillator array comprising six scintillators 11 to 16 each of which has the same shape. One half of the scintillator array (three scintillators 11 to 13) is mounted on the photomultiplier tube 21 and the other half (the other three scintillators 14 to 16) is mounted on the oth r photomultipli r tube 22. Thes scintillators 11 to 16 ar optically coupl d to one another through respective coupling surfaces 31b to 36a between the respective neighbouring scintillators.

In this scintillator array, each of the four coupling surfaces 31b, 32a, 35b and 36a which are disposed most apart from the centre of the scintillator array is designed so as to be a mirror-polished surface. Gaps between these faced coupling surfaces are filled with air. That is, each of two pairs of the neighbouring scintillators 11 and 12 and the neighbouring scintillators 15 and 16 corresponds to the third model as shown in Fig. 4(C). On the other hand, each of other four coupling surfaces 32b, 33a, 34b and 35a which are near to the centre of the scintillator array is designed to be a rough surface. Gaps between these faced coupling surfaces are also filled with air. That is, each of the two pairs of the neighbouring scintillators 12 and 13 and the neighbouring scintillators 14 and 15 corresponds to the first model as shown in Fig. 4(A). Further, each of a pair of the coupling surfaces 33b and 34a which are disposed at the centre of the scintillator array is designed to be a rough surface. The gap between the coupling surfaces is filled with an optical coupling agent having higher refractive index than air after plural scintillators are assembled into the scintillator array, or the coupling surfaces 33b and 34a are coated with the optical coupling agent before the scintillators are assembled. Accordingly, the scintillator array of this embodiment has a construction that the light-transmissivity (that is, the distribution ratio) is intermittently more increased as approaching from both sides of the scintillator array toward the centre thereof.

An identification capability (characteristic) of the radiation detector thus constructed was estimated by irradiating gamma-rays to each of the scintillators 11 to 16 of the radiation detector to emit a scintillation light in the scintillator and then obtaining output signals from the two photomultiplier tubes 21 and 22. That is, representing relative intensities of the output signals of the photomultiplier tubes 21 and 22 by P1 and P2, respectively, the identification characteristic of the radiation detector was estimated with values of DC(P1) or DC(P2) defined by the following equation:

$$DC(P1) = P1/(P1 + P2) \times 100, \text{ or } DC(P2) = P2/(P1 + P2) \times 100$$

The DC (P1) or DC(P2) mean contributive degrees of the scintillation light emitted in one scintillator to the output electrical signals of the photomultiplier tubes P1 and P2, respectively. For example, in a case of the DC(P1), the scintillation light emitted in one scintillator is distributed in a predetermined distribution ratio to all scintillators 11 to 16 and a part of the distributed scintillator light is guided through the scintillators 11 to 13 to the photomultiplier tube 21, so that an electrical signal having an intensity corresponding to the part of the scintillation light is outputted from the phot multiplier tube 21. Accordingly, a distribution ratio of the scintillation light emitted in each of th scintil-

lators to each of the photomultiplier tubes 21 and 22 is determined by detecting an output signal of each of the photomultiplier tubes 21 and 22 at the time when gamma-rays is irradiated to each of the scintillators.

A detection result of the value DC (P1) was as follows: DC(P1) = 89, 76, 61, 37, 20 and 11 for the irradiation of the gamma-rays to the scintillators 11 to 16, respectively. It is apparent from the above values of DC(P1) that the incidence of the gamma-rays to the scintillators can be positionally clearly discriminated by the two photomultiplier tubes 21 and 22. The same detection result was obtained by the photomultiplier tube 22.

Fig. 6 shows a second embodiment of the radiation detector according to this invention.

In this embodiment, the radiation detector includes a scintillator array comprising two-dimensionally arranged plural (24) scintillators 11_{11} to 11_{46}, and four photomultiplier tubes 21 to 24 each optically coupled to an equal number (6) of scintillators. This radiation detector has a construction that a plurality of one dimensionally arranged scintillator arrays (for example, in an X-direction) as shown in Fig. 5 are arranged in a Y-direction to form a two-dimensionally arranged scintillator array. Accordingly, the surface condition and the coupling condition of the neighbouring scintillators of the scintillator array of this embodiment are identical to those of the scintillator array of the first embodiment in the X-direction. In the arrangement of the scintillators in the Y-direction, six pairs of both of coupling surfaces 72b and 73a which are disposed at the centre of the scintillator array in the Y-direction and aligned with one another in the X-direction are designed to be rough surfaces, and these coupling surfaces are coated with the optical coupling agent 6 or gaps therebetween are filled with the optical coupling agent 6. On the other hand, in the other pairs of the coupling surfaces 71b and 72a (73b and 74a) which are disposed at the side portion of the scintillator array in the Y-direction, the outer coupling surfaces 71b and 74a of the respective pairs are mirror-polished while the inner coupling surfaces 72a and 73b are roughly formed. Gaps between these pairs of the coupling surfaces disposed at the side portion of the scintillator array are filled with air. This arrangement enables the four photomultiplier tubes 21 to 24 to discriminate 24 scintillators accurately.

In the above embodiments, the models as shown in Figs. 4(A) to 4(C) and 4(F) are used in combination to construct the scintillator array. However, in order to finely control the distribution ratio of the scintillation light to the other scintillators, the models as shown in Figs. 4(D) and 4(E) may be also used along or in combination with the above models. Further, in order to more finely change the light-transmissivity (distributi n ratio) of the coupling surfaces, the degree f the roughness of the rough coupling surfaces may be changed, various optical coupling agents having different refractive indexes may be used, or the optical coupling agent may be partly coated to some coupling surfaces (or filled in the gaps therebetween) and the air may be filled in the gaps between the other coupling surfaces).

Figs. 7 shows a third embodiment of the scintillator array according to this invention. The scintillator array of this embodiment comprises 6X6 (=36) scintillators arranged two-dimensionally, and four photomultipliers each of which are arranged so as to be confront with six scintillators. As shown in Fig. 7, mirror-polished surfaces are formed at the four outer side surfaces of the scintillator array to prevent leak of a scintillation light from the side surfaces to the outside and at confronting coupling surfaces (as shown by oblique lines A) nearest to the outer side surfaces. That is, a full masking (defined as a coupling portion comprising confronting coupling surfaces which are mirror-polished) is formed at the side portion of the scintillator array. On the other hand, roughened surfaces are formed at the other confronting coupling surfaces (B) (as shown by saw-shaped lines). Particularly, RTV rubber is provided between the coupling surfaces (C) at the centre of the scintillator array.

As described above, according to the radiation detector of this invention, a distribution ratio between the neighbouring coupling surfaces can be freely and finely changed with no reflection layer, so that a distribution process of a scintillation light is more effectively performed without attenuation of the light to improve energy resolution, timing resolution and crystal identification characteristic. Further, no requirement of the reflection layer enables the scintillators to be minutely arranged and thus non-sensitive region of the scintillators can be reduced. Still further, the radiation detector of this invention does not need a scintillator array having a complicated structure, and therefore manufacturing of a scintillator array can be easily performed.

Claims

1. A radiation detector for detecting the position of incident radiation, comprising:

   a scintillator array having a plurality of scintillator elements (11,...16) for generating scintillation light upon incidence of radiation to them, each scintillator element (11,...16) having a radiation receiving surface, a light-emitting surface for emitting light guided through the scintillator element (11,...16) in a first direction, and a light-distributing surface (31,...36; 71,...74) for transmitting part of the scintillation light to an adjacent scintillator element (11,...16) in a second direction, substantially perpendicular to the first direction to distribut scintillation light to other

scintillator elements (11,...16) with a pre-determined distribution ratio ; and

a plurality of photomultiplier tubes (21,...24) optically coupled to the scintillator array wherein each photomultiplier tube (21,...24) is optically coupled to the light-emitting surfaces of a plurality of scintillator elements (11,...16) for receiving the scintillation light and converting the scintillation light into an amplified electrical signal representative of the incident position of the radiation on the scintillator array;

characterised in that each of the light-distributing surfaces (31,...36;71,...74) serves as a coupling surface for optically coupling each scintillator element (11, ... 16) to an adjacent element (11, ... 16), each of the light transmitting surfaces (31, ... 36; 71, ... 74) having a roughened surface, a mirror-polished surface or both, for transmitting the scintillation light with a predetermined degree of transmissivity to control the distribution ratio of the scintillation light transmitted between from neighbouring scintillator elements.

2. A radiation detector according to claim 1, wherein each scintillator element (11, ... 16) is separated from each adjacent scintillator element (11, ... 16) by a gap.

3. A radiation detector according to claim 2, wherein the gap is filled with air or an optical coupling agent (6) having a refractive index different from that of air to further control the degree of transmissivity between adjacent scintillator elements (11, ... 16).

4. A radiation detector according to claim 3, wherein the optical coupling agent (6) is silicone oil, silicone grease, water or a combination of these.

5. A radiation detector according to any of the preceding claims, wherein at least one of the light distribution surfaces (31, ... 36; 71, ... 74) includes both a roughened surface and a mirror polished surface in a pre-determined ratio to give a degree of transmissivity different from that for either a mirror polished surface or a roughened surface.

6. A radiation detector according to claims 2 to 5, in which the light distributing surfaces (31, ... 36; 71, ... 74) have a degree of roughness controlled so that a desired degree of transmissivity between adjacent scintillator elements (11, ... 16) is achieved, the degree of transmissivity determining the distribution ratl f the scintillati n light transmitted between the adjacent scintillator elements (11, ... 16).

7. A radiation detector according to any one of the preceding claims, in which the scintillator array comprises a plurality of independent separate scintillator elements (11,...16) arranged side-by-side and separated from one another wherein the separate scintillator elements (11,...16) are optically coupled to adjacent scintillator elements (11,...16) by the light distributing surfaces (31,...36;71,...74).

8. A radiation detector according to any one of claims 2 to 7, wherein the scintillator array comprises a plurality of scintillator elements formed from a common substrate and separated from one another by a plurality of grooves which provide the distribution regions.

9. A radiation detector according to any of the preceding claims, wherein the distribution ratio between one pair of adjacent scintillator elements (11, ... 16) is different from that between another pair of adjacent scintillator elements (11, ... 16).

10. A radiation detector according to any of the preceding claims, in which some of the gaps between adjacent scintillator elements contain air, and others of the gaps between adjacent scintillator elements (11, ... 16) contain an optical coupling agent (6).

Patentansprüche

1. Strahlungsdetektor zum Detektieren der Position einer auftreffenden Strahlung mit
einer Szintillatormatrix mit einer Vielzahl von Szintillatorelementen (11..16) zur Erzeugung von Szintillationslicht beim Auftreffen der Strahlung auf die Szintillatorelemente, wobei jedes Szintillatorelement (11..16) eine Strahlungsaufnahmefläche, eine Lichtemittierende Fläche zum Emittieren von durch das Szintillatorelement (11..16) in einer ersten Richtung geführtem Licht und eine Lichtverteilungsfläche (31..36; 71..74) zur Übertragung eines Teiles des Szintillationslichtes auf ein benachbartes Szintillatorelement (11..16) in einer zweiten Richtung, die im wesentlichen senkrecht zur ersten Richtung verläuft, um Szintillationslicht auf andere Szintillatorelemente (11..16) mit einem vorgegebenen Verteilungsverhältnis zu verteilen, aufweist; und
einer Vielzahl von Fotovervielfacherröhren (21..24), die optisch mit der Szintillatormatrix gekoppelt sind, wobei jede Fotovervielfacherröhre (21..24) optisch mit den Licht-emittierenden Flächen einer Vielzahl von Szintillatorelementen (11..16) gekoppelt ist, um das Szintillationslicht aufzunehmen und in ein verstärktes elektrisches

Signal zu überführen, das die Position des Auftreffens der Strahlung auf die Szintillatormatrix kennzeichnet;
dadurch gekennzeichnet, daß jede der Lichtverteilungsflächen (31..36; 71..74) als Kopplungsfläche zum optischen Koppeln eines jeden Szintillatorelementes (11..16) mit einem benachbarten Element (11..16) dient und daß jede der Lichtübertragungsflächen (31..36; 71..74) eine aufgerauhte Fläche, eine hochglanzpolierte Fläche oder beide aufweist, um das Szintillationslicht mit einem vorgegebenen Grad an Durchlässigkeit zu übertragen und das Verteilungsverhältnis des zwischen benachbarten Szintillatorelementen übertragenen Lichtes zu steuern.

2. Strahlungsdetektor nach Anspruch 1, bei dem jedes Szintillatorelement (11..16) von jedem benachbarten Szintillatorelement (11..16) durch einen Spalt getrennt ist.

3. Strahlungsdetektor nach Anspruch 2, bei dem der Spalt mit Luft oder einem optischen Kopplungsmittel (6), das einen von Luft verschiedenen Brechungsindex aufweist, gefüllt ist, um den Grad der Durchlässigkeit zwischen benachbarten Szintillatorelementen (11..16) weiter zu steuern.

4. Strahlungsdetektor nach Anspruch 3, bei dem das optische Kopplungsmittel (6) Silikonöl, Silikonfett, Wasser oder eine Kombination dieser Substanzen ist.

5. Strahlungsdetektor nach einem der vorangehenden Ansprüche, bei dem mindestens eine der Lichtverteilungsflächen (31..36; 71..74) sowohl eine aufgerauhte Fläche als auch eine hochglanzpolierte Fläche in einem vorgegebenen Verhältnis aufweist, um einen Grad an Durchlässigkeit zu erhalten, der sich von dem für eine hochglanzpolierte Fläche oder eine aufgerauhte Fläche unterscheidet.

6. Strahlungsdetektor nach den Ansprüchen 2 bis 5, bei dem die Lichtverteilungsflächen (31..36; 71..74) einen Grad an Rauhigkeit besitzen, der so gesteuert ist, daß ein gewünschter Grad an Durchlässigkeit zwischen benachbarten Szintillatorelementen (11..16) erreicht wird, wobei der Grad an Durchlässigkeit das Verteilungsverhältnis des zwischen den benachbarten Szintillatorelementen (11..16) übertragenen Szintillationslichtes bestimmt.

7. Strahlungsdetektor nach einem der vorangehenden Ansprüche, bei d m die Szintillat rmatrix eine Vielzahl von unabhängigen separaten Szintillatorelementen (11..16) aufweist, die Seite an Seite angeordnet und voneinander getrennt sind, wobei diese separaten Szintillatorelemente (11..16) durch die Lichtverteilungsflächen (31..36; 71..74) mit benachbarten Szintillatorelementen (11..16) optisch gekoppelt sind.

8. Strahlungsdetektor nach einem der Ansprüche 2 bis 7, bei dem die Szintillatormatrix eine Vielzahl von Szintillatorelementen umfaßt, die aus einem gemeinsamen Substrat gebildet und durch eine Vielzahl von Nuten, die die Verteilungsbereiche bilden, voneinander getrennt sind.

9. Strahlungsdetektor nach einem der vorangehenden Ansprüche, bei dem das Verteilungsverhältnis zwischen einem Paar von benachbarten Szintillatorelementen (11..16) von dem zwischen einem anderen Paar von benachbarten Szintillatorelementen (11..16) verschieden ist.

10. Strahlungsdetektor nach einem der vorangehenden Ansprüche, bei dem einige der Spalte zwischen benachbarten Szintillatorelementen Luft enthalten, während andere Spalte zwischen benachbarten Szintillatorelementen (11..16) ein optisches Kopplungsmittel (6) enthalten.

Revendications

1. Détecteur de rayonnement permettant de détecter la position d'un rayonnement incident, comprenant :

un réseau de scintillateurs comportant une pluralité d'éléments de scintillateur (11, ..., 16) pour générer une lumière de scintillation suite à l'arrivée en incidence d'un rayonnement dessus, chaque élément de scintillateur (11, ..., 16) comportant une surface de réception de rayonnement, une surface émettrice de lumière pour émettre une lumière guidée au travers de l'élément de scintillateur (11, ..., 16) suivant une première direction et une surface de distribution de lumière (31, ..., 36 ; 71, ..., 74) pour transmettre une partie de la lumière de scintillation à un élément de scintillateur adjacent (11, ..., 16) suivant une seconde direction sensiblement perpendiculaire à la première direction afin de distribuer la lumière de scintillation à d'autres éléments de scintillateur (11, ..., 16) avec un rapport de distribution prédéterminé ; et

une pluralité de tubes photomultiplicateurs (21, ..., 24) couplés optiquement au réseau de scintillateurs, dans lequel chaque tube photomultiplicateur (21, ..., 24) est couplé optiquement aux surfaces émettrices de lumière d'une plura-

lité d'éléments de scintillateur (11, ..., 16) pour recevoir la lumière de scintillation et pour convertir la lumière de scintillation en un signal électrique amplifié représentatif de la position d'incidence du rayonnement sur le réseau de scintillateurs ;

caractérisé en ce que chacune des surfaces de distribution de lumière (31, ..., 36 ; 71, ..., 74) joue le rôle de surface de couplage pour coupler optiquement chaque élément de scintillateur (11, ..., 16) à un élément adjacent (11, ..., 16), chacune des surfaces de transmission de lumière (31, ..., 36 ; 71, ..., 74) comportant une surface rendue rugueuse, une surface polie miroir ou les deux pour transmettre la lumière de scintillation avec un degré prédéterminé de transmissivité pour commander le rapport de distribution de la lumière de scintillation transmise entre depuis des éléments de scintillateur voisins.

2. Détecteur de rayonnement selon la revendication 1, dans lequel chaque élément de scintillateur (11, ..., 16) est séparé de chaque élément de scintillateur adjacent (11, ..., 16) par un espace.

3. Détecteur de rayonnement selon la revendication 2, dans lequel l'espace est rempli d'air ou d'un agent de couplage optique (6) présentant un indice de réfraction différent de celui de l'air pour commander davantage le degré de transmissivité entre des éléments de scintillateur adjacents (11, ..., 16).

4. Détecteur de rayonnement selon la revendication 3, dans lequel l'agent de couplage optique (6) est de l'huile silicone, de la graisse silicone, de l'eau ou une combinaison de celles-ci.

5. Détecteur de rayonnement selon l'une quelconque des revendications précédentes, dans lequel au moins l'une des surfaces de distribution de lumière (31, ..., 36 ; 71, ..., 74) inclut à la fois une surface rendue rugueuse et une surface polie miroir selon un rapport prédéterminé pour obtenir un degré de transmissivité différent de celui de soit une surface polie miroir soit une surface rendue rugueuse.

6. Détecteur de rayonnement selon les revendications 2 à 5, dans lequel les surfaces de distribution de lumière (31, ..., 36 ; 71, ..., 74) présentent un degré de rugosité commandé de telle sorte qu'un degré souhaité de transmissivité entre des éléments de scintillateur adjacents (11, ..., 16) soit obtenu, le degré de transmissivité déterminant le rapport de distribution de la lumière de scintillation transmis entr les éléments de scintillateur adjacents (11, ..., 16).

7. Détecteur de rayonnement selon l'une quelconque des revendications précédentes, dans lequel le réseau de scintillateurs comprend une pluralité d'éléments de scintillateur séparés indépendants (11, ..., 16) agencés côte-à-côte et séparés les uns des autres, dans lequel les éléments de scintillateur séparés (11, ..., 16) sont couplés optiquement à des éléments de scintillateur adjacents (11, ..., 16) par les surfaces de distribution de lumière (31, ..., 36 ; 71, ..., 74).

8. Détecteur de rayonnement selon l'une quelconque des revendications 2 à 7, dans lequel le réseau de scintillateurs comprend une pluralité d'éléments de scintillateur formés à partir d'un substrat commun et séparés les uns des autres par une pluralité de gorges qui constituent les régions de distribution.

9. Détecteur de rayonnement selon l'une quelconque des revendications précédentes, dans lequel le rapport de distribution pour une paire d'éléments de scintillateur adjacents (11, ..., 16) est différent de celui pour une autre paire d'éléments de scintillateur adjacents (11, ..., 16).

10. Détecteur de rayonnement selon l'une quelconque des revendications précédentes, dans lequel certains des espaces séparant des éléments de scintillateur adjacents contiennent de l'air et d'autres espaces séparant des éléments de scintillateur adjacents (11, ..., 16) contiennent un agent de couplage optique (6).

FIG. 3

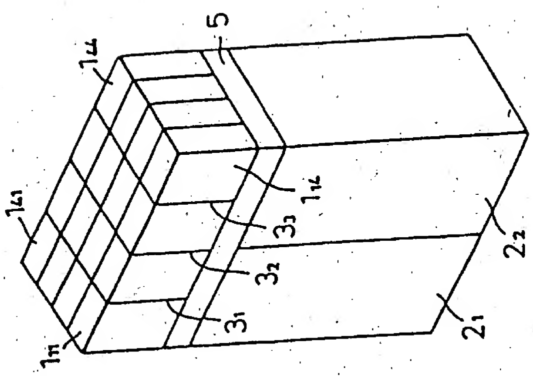


FIG. 2

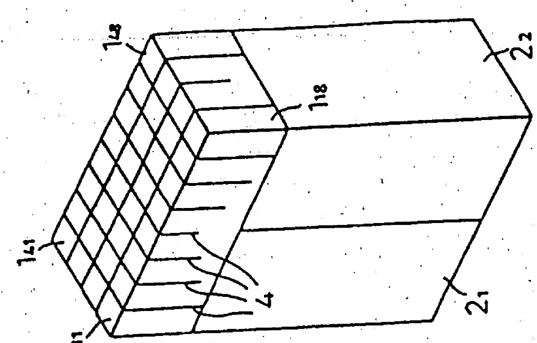


FIG. 1

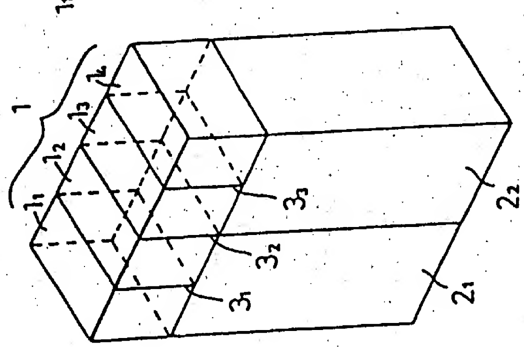


FIG. 6

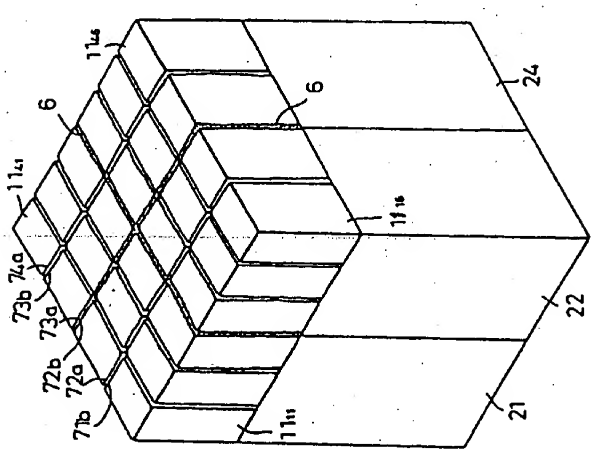


FIG. 5

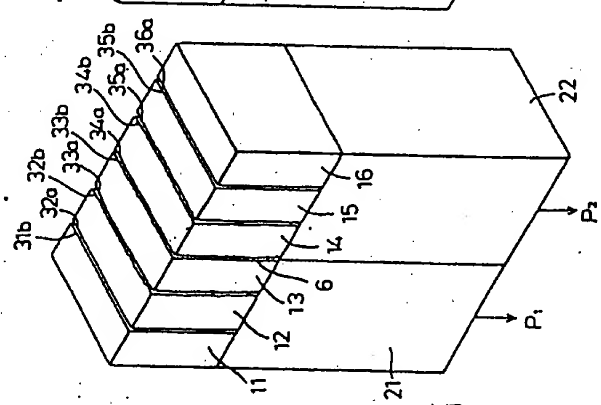


FIG. 4(A) FIG. 4(B) FIG. 4(C) FIG. 4(D) FIG. 4(E) FIG. 4(F)